

# Iberian acid peatlands: types, origin and general trends of development

X. Pontevedra-Pombal<sup>1</sup>, D. Castro<sup>2</sup>, R. Carballeira<sup>2</sup>, M. Souto<sup>2</sup>, J.A. López-Sáez<sup>3</sup>,  
S. Pérez-Díaz<sup>3</sup>, M.I. Fraga<sup>2</sup>, M. Valcárcel<sup>4</sup> and E. García-Rodeja<sup>1</sup>

<sup>1</sup>Department of Soil Science and Agricultural Chemistry and <sup>2</sup>Department of Botany,  
Faculty of Biology, University of Santiago de Compostela, Galicia, Spain

<sup>3</sup>GI Archaeobiology, Institute of History, CCHS-CSIC, Madrid, Spain

<sup>4</sup>Department of Geography, Faculty of Geography and History, University of Santiago de Compostela, Galicia, Spain

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## SUMMARY

In the present study we reviewed the genesis, development and classification of peatlands in the Iberian Peninsula by conducting chronostratigraphic analysis of 108 of these ecosystems. The findings are summarised as follows:

1. The region has a wide variety of peatlands which are classified according to their biogeochemical, geomorphological and ecological characteristics into different types of bogs and fens.
2. Most of the peatlands occur in the Atlantic region followed by the Mediterranean and Alpine regions. Fens are more widely distributed than bogs, and blanket and raised bogs are mainly found in the Eurosiberian biogeographical region.
3. In many of the fens, the last active peat-forming cycle occurred during the Late Holocene (43 %). In most of the bogs, the peat-forming cycle occurred in the Middle Holocene (70 %), although in a substantial proportion of blanket bogs these processes occurred in the Early Holocene (30 %).
4. The peat formed in the last active cycle is, on average, thicker in raised bogs (322 cm) than in blanket bogs (257 cm) and fens (156 cm).
5. Vertical peat accumulation rates varied between 16 and 30 yr cm<sup>-1</sup> in more than 40 % of the peatlands. The accumulation rates differed significantly between the different types of peatlands and were highest in the raised bogs. The accumulation rates were very variable in the fens.
6. The genesis, evolution and types of Iberian peatlands are similar to those observed in peatlands in northern latitudes in Europe and North America.

**KEY WORDS:** chronology, distribution of mires, Holocene, Iberian Peninsula, peat accumulation

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## INTRODUCTION

Amongst the many important environmental services provided by peatlands, their capacity to accumulate carbon with a positive feedback to the climate system (Limpens *et al.* 2008), and their ability to act as natural archives of environmental evolution, have captured the attention of researchers.

The carbon accumulated in organic soils worldwide (>600 Gt C since the Last Glacial Maximum; Yu *et al.* 2010) represents up to 50 % of the terrestrial reserve (Evans *et al.* 2006) and the equivalent of more than 60 % of the atmospheric reserves of carbon (Freeman *et al.* 2001). However, there is some latitudinal asymmetry in these reserves, determined by the effects of macroclimatic factors.

In the last ~150 years, peatlands (fens and bogs)

have played an important role in increasing our knowledge of the environmental evolution of the planet (Blackford 2000, Bindler *et al.* 2008, Chambers *et al.* 2010). The study of peatlands has enabled archives of palaeoenvironmental information to be linked to the current status, evolution and projected status of these ecosystems within the context of developing strategies for sustainable management of the natural environment. With these aims, many scientific disciplines use various proxy measures, component analysis and other properties to help understand the patterns of change in the intensity and rhythm of development and geographical scale of distribution of peatland ecosystems.

Of the world's wetlands, 50 % are peatlands (Joosten & Clarke 2002), and most of these are found in northern latitudes (*i.e.* north of 45 °N; Loisel *et al.*

2014). This fact, together with a certain degree of misleading information about the distribution of blanket and raised bogs (key to the study of terrestrial C and palaeoenvironmental evolution) has led to sparse attention being given to peatlands in the Iberian Peninsula. These peatlands have often been presented as being rare, poorly developed, with low rates of peat accumulation and only minerotrophic subtypes (Maltby & Proctor 1996, Raeymaekers 1999, Evans 2006).

The border zone between the Eurosiberian and Mediterranean regions is regarded as extremely sensitive to climate change. This is of some importance in relation to the distribution of different types of peatlands, as well as to biological or climate-related diversity and palaeoclimatic patterns. The peatlands in this zone mainly occur in mountainous areas, in the floodplains of large hydrographical basins and on some low-energy coastal platforms. Although the European Union (EU) peatland report (Byrne *et al.* 2004) indicates that peatlands occupy an area of 8000 ha in the Iberian Peninsula, the minimum area estimated in a recent study is around 18000–22000 ha (Heras *et al.* 2017). In the north of the Iberian Peninsula, particularly in the NW, there is a large cohort of different types and subtypes of acid peatlands; these include blanket bog (watershed bog, valley-side bog, spur bog, saddle bog), raised bogs (semiconfined raised bog, unconfined raised bog) and fens (glacial fen, endorheic fen, slope fen, fluvial fen, topogenic fen). The particular geographical location of the Iberian Peninsula within Europe, the distribution of ecosystems and their characteristics within the general climate model, and the lack or scarcity of old trees coupled with geographical restrictions on the occurrence of other environmental archives (including ice and lakes), make the Iberian peatlands an essential tool for understanding Holocene environmental evolution in southern Europe (Pontevedra-Pombal *et al.* 2006).

The aim of the present study is to evaluate the existence of common and/or specific patterns in the evolution of Iberian peatlands in relation to the general trends of Holocene development of peatlands in the Northern Hemisphere, *via* an exhaustive review of published information on the genesis and development of these ecosystems.

## STUDY AREA

The Iberian Peninsula, the westernmost peninsula in southern Europe, is located at the southern edge of the temperate latitudes in the Northern Hemisphere (between 43° 47'–36° 00' N and 9° 30' W–3° 19' E).

The peninsula is surrounded by the Mediterranean Sea and the Atlantic Ocean in a proportion of 6/7 along the 4872 km of coastline. It is joined to the rest of the European continent by an isthmus to the north-east, constituted by the Pyrenean mountain range which extends uninterrupted from the Mediterranean Sea to the Bay of Biscay. The mean altitude of the whole peninsula is 600 m a.s.l. Around two-thirds of its total surface area is covered by a high-altitude plain, and this structure is surrounded by mountain chains whose peripheral positions largely determine climatic characteristics, with a marked continental influence towards the interior of the peninsula.

The Eurosiberian bioregion extends from northern Portugal through Galicia, Asturias, Cantabria, the Basque Country and the western and central Pyrenees (Figure 1). It is characterised by a wet climate, moderated by the oceanic influence, with temperate-cold winters and no clearly defined dry season. The Mediterranean bioregion incorporates all inland plateaus and mountains as well as the Mediterranean basin zones

The geographical isolation of the Iberian Peninsula, combined with its crossroads position and its geological and orographic complexity, has led to the development of an area of great diversity with strong physical, climatic, geomorphological and edaphic contrasts. Its complex environmental history is the result of geodynamic activity from ancient to more recent times, linked to the presence of active plate boundaries (Vera 2004). From the point of view of lithology, the geological substrate has traditionally been classified into three large groups: the siliceous materials that dominate the western Iberian Peninsula, the limestones in the eastern zone associated with the Alpine orogeny, and the clay substrates in inland depressions (Melendez & Fuster 2003), although the details may be very complex at finer scales (Vera 2004).

The flora and fauna reflect these conditions and include a large number of endemic taxa. As a result of its position on an important route between Africa and Europe, the Iberian Peninsula has been enriched by the arrival of a variety of flora including steppe, thermophilic, xerophytic, orophile and boreo-alpine plants. Many of these plants have survived thanks to the diversity of environments offered by the mountain ranges enabling them to extend their distributions to higher altitudes when the climate became too hot and to lower altitudes when it became too cold. The geological complexity of most of the Iberian mountains greatly increased the number of new environments to which plants were able to adapt, thus increasing the diversity and richness of the flora.

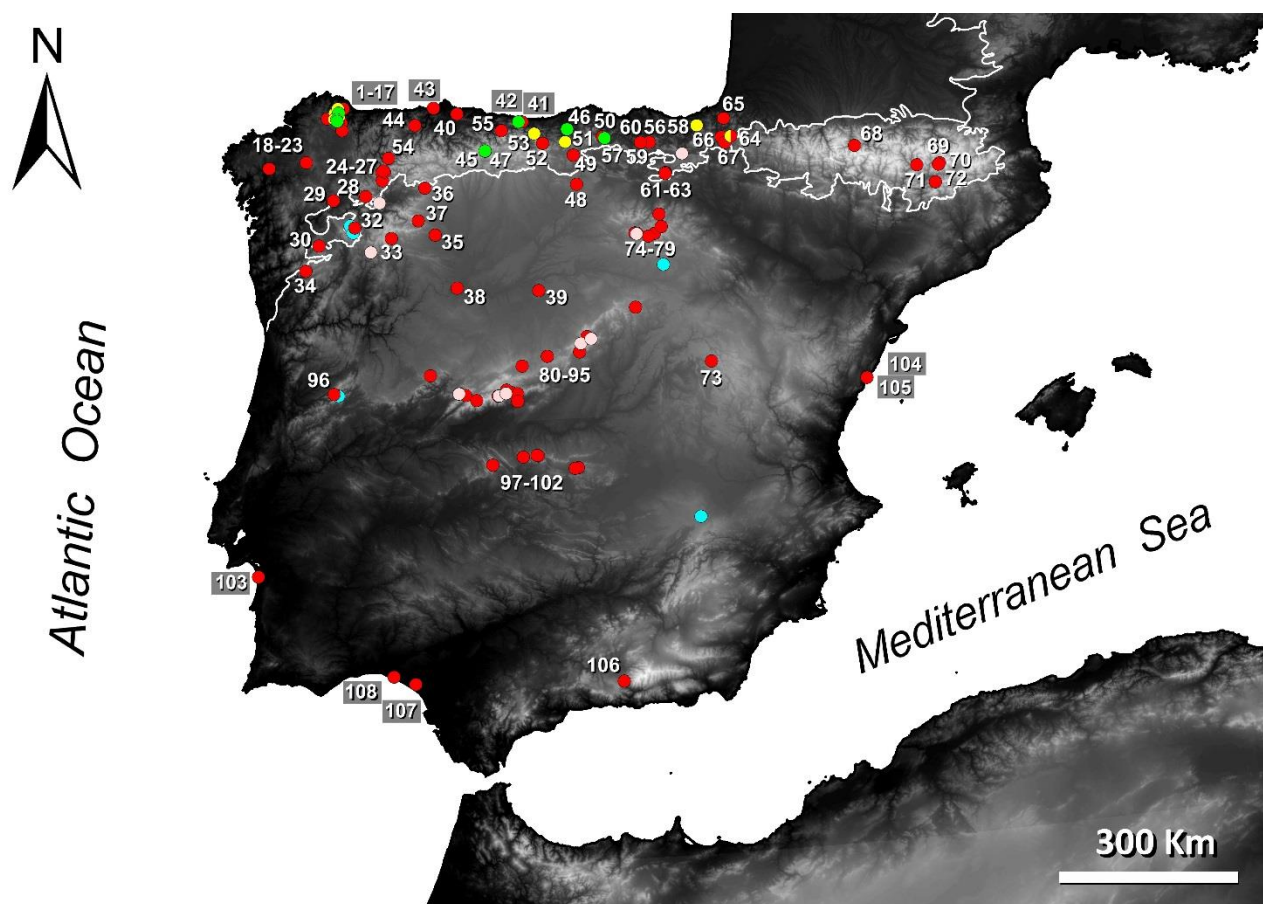


Figure 1. Geographical location of the 108 peatlands analysed. Sequence numbers refer to the Appendix. Red circles: fens; green circles: blanket bogs; yellow circles: raised bogs; blue circles: para-peaty soils; pink circles: peatlands without  $^{14}\text{C}$  data. The white line separates the Eurosiberian, Mediterranean and Alpine bioregions.

## METHODS

### Documentary information

In order to create a database of information on the genesis and development of peatlands on the Iberian Peninsula, we reviewed all of the data available in scientific articles, doctoral theses, books and technical reports published between 1950 and 2016. Only those sites that could be verified as peatlands were included in the database. The criteria proposed by Loisel *et al.* (2014) were used to distinguish between peat and non-peat material (gyttja, inorganic horizons rich in organic matter, carbonaceous lacustrine sediments, *etc.*).

Systems that we identified as para-peaty soils, palaeo-peat horizons, salt marshes, lacustrine and fluvial ecosystems with buried peat profiles or sediments, and mineral soils rich in organic matter were not included in the study, even if they were referred to as peatlands in the original publications. Peatlands for which no radiocarbon data were available were also excluded from the study. These

peatlands, numbering eleven out of the 119 identified (see Menéndez Amor & Florschütz 1961, Menéndez Amor 1971, Ruiz Zapata & Acaso Deltell 1981, Jiménez Ballesta *et al.* 1985, Atienza Ballano 1993, Ramil-Rego & Aira Rodríguez 1993a, 1994; Peñalba 1994, Gil García *et al.* 1995, Muñoz Sobrino 2001), are acid fens distributed homogeneously throughout the Iberian geography (Figure 1) with sparse development and/or subject to intense mechanisms of detrital deposition of colluvial-alluvial origin. As only a small number of peatlands belonging to the best-represented types in this study were discarded for lack of chronological control, the potential effect of their exclusion on the data obtained can be disregarded.

The following data were recorded for each of the 108 peatlands selected: vernacular place name, geographical area, type and subtype of peatland, location, altitude, bioclimatic zone, lithology of the geological formation, age and depth of the last active peat-forming cycle, and the total depth of unconsolidated material before peat formation. This information is summarised in Figure 1 and the Appendix.

The last (current) active peat-forming cycle was taken to have begun when stratigraphical features (colluvial or alluvial deposits, burned horizons, stone lines) and/or the age-depth model indicated the existence of a hiatus in development of the peatland.

### Dating and chronology

All of the radiocarbon dates reported in the literature reviewed, for which a stratigraphical control was included, were recalibrated in order to establish the chronological patterns of peatland development. The  $^{14}\text{C}$  dates were calibrated using the CALIB 7.1 radiocarbon calibration program (Stuiver *et al.* 2015). Ages were expressed as calibrated years before present (cal yr BP), assuming the values obtained for the range of maximum probability 2 sigma intervals, which is considered to be a robust statistical value (Telford *et al.* 2004).

### Peat accumulation rates

Vertical peat accumulation rates (PAR;  $\text{yr cm}^{-1}$ ) were calculated for all peatlands analysed in this study by

considering the basal age and thickness of the last continuous, active peat-forming cycle.

### Statistical analysis

Statistical analysis (SPSS Statistics software 20) was performed to identify the central values and dispersion for the population under study. A nonparametric Kruskal-Wallis test was used to identify significant differences between the peatlands. The minimum accepted value of significance was  $p < 0.05$ .

## RESULTS

### Distribution of Iberian peatlands

Examination of the literature including information about the genesis, morphostratigraphy, chronology and classification of the peatlands on the Iberian Peninsula indicates that, of the 108 peatlands selected, 84 % are fens and only 16 % are raised or blanket bogs (Figure 2). Following the classification

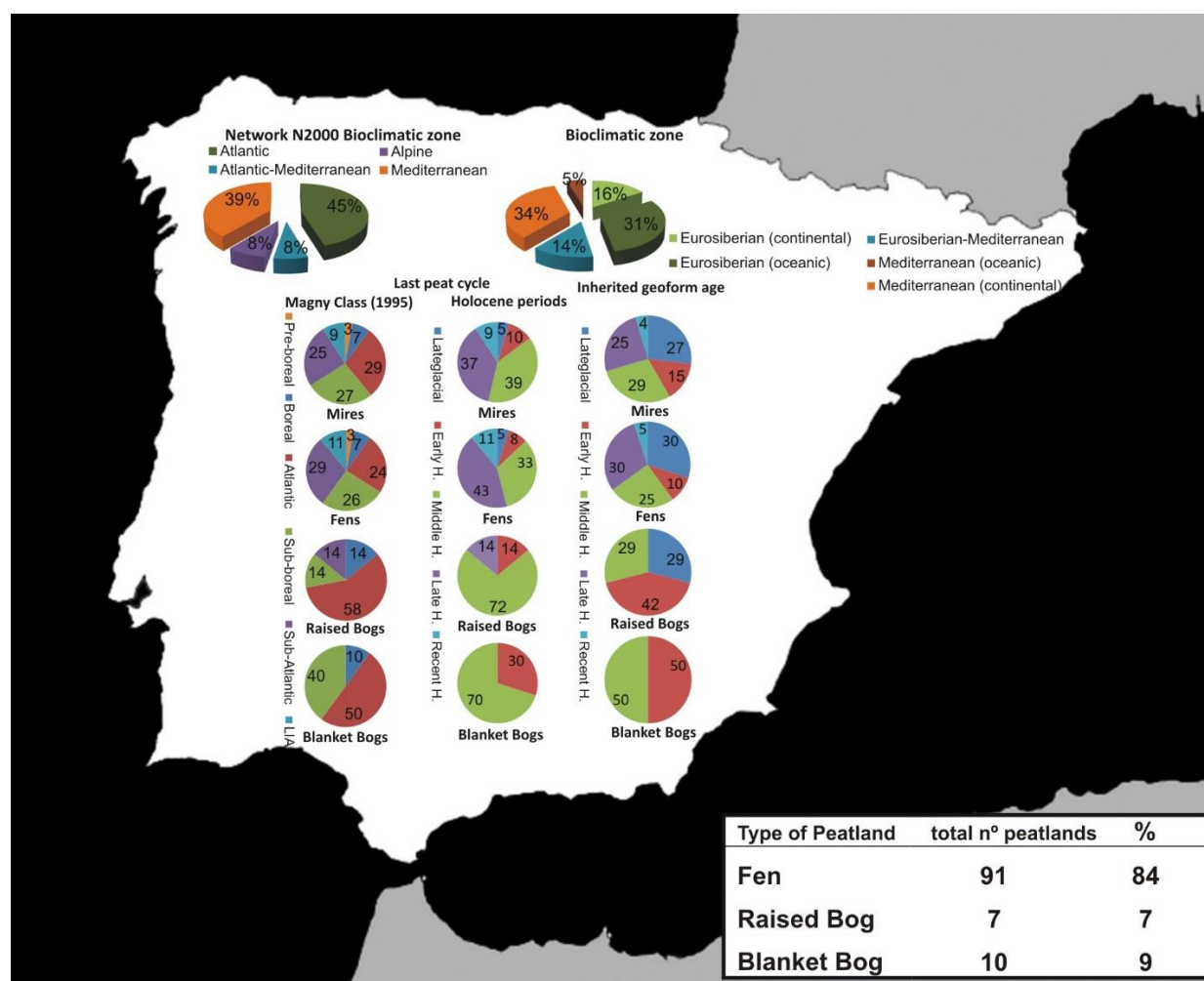


Figure 2. Typological, chronological and geographical distribution of peatlands in the Iberian Peninsula.

of biogeographical regions established in the Natura 2000 network (European Commission 2016), 45 % of the peatlands are included in the Atlantic region, 39 % in the Mediterranean region and 8 % in the Alpine region. Continental peatlands are the most numerous type in the Mediterranean region, and peatlands with oceanic influence are the most abundant in the Eurosiberian region (Figure 2).

In accordance with the Holocene palaeoecological zonation, and considering the modification proposed by Magny (1995), the last (current) peat-forming cycle was grouped into the following classes: >10000 years (>11500 cal BP), pre-Boreal; 10000–8000 years (11500–8850 cal BP), Boreal; 8000–5000 years (8850–5700 cal BP), Atlantic; 5000–2500 years (5700–2600 cal BP), sub-Boreal; and 2500–600 years (2600–600 cal BP), sub-Atlantic. A special class was also included to describe peatlands developed within the last 600 years - a period during which remarkable climatic variations occurred (Little Ice Age: LIA), the industrial revolution flourished, and anthropic modification of the environment was amplified. The interaction between anthropic and natural factors increased exponentially during this period, generating significant changes in the evolution of peatlands.

The chronostratigraphy reported in the literature reviewed showed that 29 % of the Iberian peatlands date from the Atlantic period, 27 % are sub-Boreal and 25 % are sub-Atlantic, 9 % originated in the LIA, 7 % are derived from the Boreal period, and only 3 % have remained active since the pre-Boreal period (Figure 2). The chronological classification of fens is, in general, very similar to that obtained for all of the peatlands (fens and bogs) studied, with a slight predominance of systems of sub-Atlantic origin (29 %). However, the pattern is very different for the bogs, especially the blanket bogs. In both cases, ombrotrophic peat formation was not initiated in the pre-Boreal or LIA periods. In almost 60 % of the raised bogs and in most of the bogs in general, formation of ombrotrophic peat began during the Atlantic period (Figure 2).

When the peatlands were grouped in relation to the last cycle of continuous peat formation, following the chronological classification proposed by Walker *et al.* (2012) for the Holocene (>10000 years, late-glacial; 10000–8200 years, early Holocene; 8200–4200 years, middle Holocene; 4200–600 years, late Holocene; <600 years, recent Holocene), the data revealed that 39 % of the peatlands correspond to the middle Holocene and 37 % to the late Holocene. The fens were grouped in a similar way, although a slightly higher proportion were formed in the late Holocene. In contrast, most of the bogs (70 %) were

formed in the middle Holocene, and a significantly higher proportion of blanket bogs (30 %) were initiated in the early Holocene.

The sedimentary, geomorphological and edaphic processes that generated the structures leading to activation of the primary mechanisms of mire formation, terrestrialisation and paludification (Ruppel *et al.* 2013) in the Iberian peatlands are of heterogeneous origin. The processes originated in the late-glacial (27 %), middle Holocene (29 %), late Holocene (25 %), early Holocene (15 %) and recent Holocene (4 %). In fens, the processes generally originated in the late-glacial (30 %) or late Holocene (30 %). In raised bogs, the processes originated in the early Holocene (42 %). In blanket bogs, the formation processes began in the early Holocene (50 %) or the middle Holocene (50 %).

### Peat accumulation rates in Iberian peatlands

The information collected on Iberian peatlands, and incorporated into the database used in this study, was examined to determine the thickness of the most recently-formed peat cycle (RPC, cm), which was used to calculate the vertical peat accumulation rate (PAR; yr cm<sup>-1</sup>) (Table 1).

Table 1. Vertical peat accumulation rates (PAR) and thickness of the most recently-formed peat cycle (RPC) for different peatland types.

		PAR (yr cm <sup>-1</sup> )	RPC thick (cm)
<b>Fen (91)</b>	mean	38	156
	S.D.	25	105
	min	5	30
	max	167	580
<b>Raised Bog (7)</b>	mean	24	322
	S.D.	9	246
	min	11	80
	max	40	847
<b>Blanket Bog (10)</b>	mean	34	257
	S.D.	21	108
	min	16	60
	max	91	415



The mean RPC thickness values were 322, 257 and 156 cm for raised bogs, blanket bogs and fens, respectively, and the values obtained for blanket bogs were the least variable. The maximum depths of the fens and blanket bogs were around 5 m, and that of the raised bogs around 9 m; the minimum depths were around 30, 60 and 80 cm respectively.

The lowest mean PAR (most rapid accumulation) value of 24 yr cm<sup>-1</sup> corresponded to the raised bogs, and values as low as 11 yr cm<sup>-1</sup> were determined for this type of peatland. The mean PARs in fens and blanket bogs were 38 and 34 yr cm<sup>-1</sup> respectively, although the range was much greater in the fens (5–167 yr cm<sup>-1</sup> versus 16–91 yr cm<sup>-1</sup>).

The PARs were much more variable in the fens (Figure 3), with a median value of 33 yr cm<sup>-1</sup>, although most of the values are concentrated in the first quartile, which starts at 20 yr cm<sup>-1</sup>. The opposite was observed for raised bogs, with most values very close to the median (25 yr cm<sup>-1</sup>) and the maximum and minimum values close to the first and third quartiles, respectively.

Outliers (mild and critical) in the accumulation rates data were identified for the three types of peatland (Figure 3). In all cases except one, the outlier PARs were significantly higher (i.e. the accumulation rates were lower) than for the whole class. Only the atypical value found for the Chao de Veiga Mol raised bog indicated a faster accumulation rate than that for the whole class.

Classification of the peatlands on the basis of the PARs (Figure 4) showed that the most common class

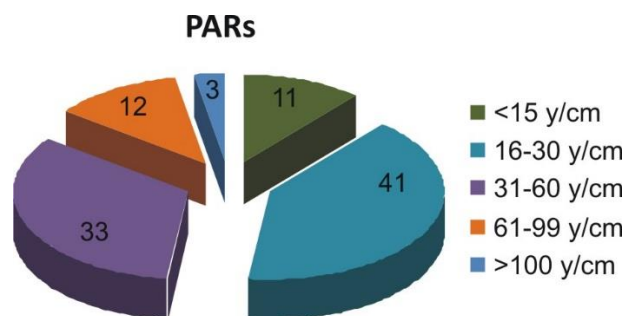


Figure 4. Distribution of the peatlands considered, grouped into different classes on the basis of vertical peat accumulation rates (PARs).

(PAR range: 16–30 yr cm<sup>-1</sup>) represented 41 % of all types. Combining this class with the second most abundant class (PAR range: 31–60 yr cm<sup>-1</sup>) accounted for 74 % of all types. The class containing the peatlands with the lowest PARs (<15 yr cm<sup>-1</sup>) accounted for less than 11 % of the total.

However, in terms of sensitivity and establishment of an ideal environmental archive, the number of peatlands with high peat accumulation rates within this class decreased greatly with age (Table 2), and only one (the Chao Mol Veiga raised bog) had a mean PAR of less than 15 yr cm<sup>-1</sup> for the entire Holocene. The results also indicated that only those peat-forming cycles associated with the LIA in five Iberian peatlands had PARs of less than a decade *per* centimetre (Table 3).

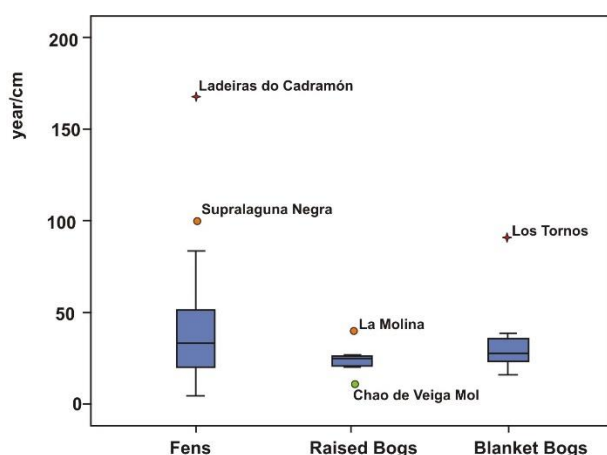


Figure 3. Vertical peat accumulation rates in the Iberian peatlands considered in this study. Stars indicate severe outliers. Circles indicate outliers with slightly higher (orange) and slightly lower (green) accumulation rates than the median.

Table 2. Number and percentage of all peatlands considered as belonging to Class 1 of vertical peat accumulation rates (<15 yr cm<sup>-1</sup>), grouped by different periods of the Holocene (yr cal BP).

PAR_Class1	Total number of peatlands	%
last 500 yr cal BP	12	11
last 1000 yr cal BP	5	5
last 2000 yr cal BP	5	5
last 5000 yr cal BP	3	3
last 10000 yr cal BP	1	0.9

Table 3. Iberian peatlands with PARs of one centimetre in less than a decade. LIA = Little Ice Age.

MIRE	Sector	Type	Holocene Period	PARs yr cm <sup>-1</sup>
CHAO DE VEIGA MOL	Serras Septentrionais	Raised bog	LIA	5.9
TURBERA DE LA PIEDRA	Cordillera Cantábrica	Fen	LIA	4.5
TURBERA DE CULAZÓN	Cordillera Cantábrica	Fen	LIA	5.9
LAGUNA NAVA	Sistema Ibérico	Fen	LIA	5.6
TURBERA DE LAS LANCHAS	Montes de Toledo	Fen	LIA	7.7

## DISCUSSION

Within the context of the northern hemisphere, in North America the origin of the geoforms of many peatlands is pre-Holocene, although stabilisation of cycles of peat formation and expansion of the peatlands were established between 10000 and 4000 yr BP (around 11500–4500 yr cal BP) (Gorham & Janssens 1992) with a peak between 8000 and 7000 yr cal BP (Gorham *et al.* 2007, MacDonald *et al.* 2006). In NW Europe, two periods of genesis and expansion of peatlands have also been established: between *ca.* 10200 and 8800 yr cal BP, coinciding with an increase in temperature and moisture, and between 7000 and 5500 yr cal BP, coinciding with a strong increase in moisture that favoured the expansion of raised bogs (Sjörs 1982, Averdick *et al.* 1993, Laine *et al.* 1996, Mäkilä 1997, Hughes & Barber 2003). Chronological studies consistently establish the genesis of European blanket bogs within the period 7000 to 1500 yr cal BP (Malmer 1975, Moore *et al.* 1984, Gallego-Sala *et al.* 2015).

The findings of the present study show that the palaeoforms (landforms, soils, sediments, deposits) generated during the late-glacial (> 10000 years), the middle Holocene (8200 to 4200 years) and the late Holocene (4200 to 600 years) stimulated (in similar proportions) the genesis of most of the Iberian fens, with structures from the early Holocene (10000–8200 years) and the recent Holocene (< 600 years) being much more scarce. However, genesis of the bogs was more strongly influenced by periglacial and alluvial processes that generated gentler slopes and the formation of horizontal surfaces prone to paludification during the early Holocene and, to a lesser extent, the middle Holocene and the late-glacial.

The stabilisation of these inherited palaeoforms determined the subsequent development of peatlands.

Peat formation was initiated immediately in some cases, whereas in others there was a delay of hundreds of years. Thus, peat formation in the Iberian peatlands may have involved a single continuous cycle extending until the present day. But it may also have taken place during resistaxia-biostaxia cycles (Erhart 1951), with erosive phases causing the loss or burial of pre-existing soils alternating with phases that reactivated soil formation processes that, in favourable environments, resulted in the initiation of new cycles of peat formation. The continuous, currently active peat-forming cycles identified in the bogs mainly originated from the early–middle Holocene. By contrast, the last peat-forming cycles in the fens predominantly (more than 75 % of the total) originated in the middle Holocene and the late Holocene, with very few cycles originating in the late-glacial, early Holocene or recent Holocene. The periodicity in the Iberian fens is similar to, although chronologically more variable than, that established by Cubizolle *et al.* (2003) for fens in the Massif Central (France).

Our analysis of Iberian peatlands revealed highly significant differences ( $p < 0.01$ – $0.005$ ) in peat thickness between peatland types. Average peat depth increased in the following order: sloping fens < glacial fens < endorheic fens < blanket bogs < raised bogs. Significant differences were also observed in the relationship between the total thickness of the deposit and the thickness of peat formed during one cycle, *i.e.* the delay in the initiation of peat formation. The delay was shortest in blanket bogs, followed by endorheic fens and raised bogs, then sloping fens and finally glacial fens.

The development of many European peatlands is linked to paludification processes and their influence on pre-existing soils; this applies to several phases of the Holocene. These processes have been linked to strong anthropic effects on the landscape (Chambers

1988, Huang 2002), cyclic climatic crises (Taylor 1983, Tipping 2008, Gallego-Sala *et al.* 2015) and/or soil evolution processes (Mitchell 1972, Bennett *et al.* 1992). Initiation of the formation of most of the Iberian peatlands coincided with forest decline, increased numbers of erosion events in soils, increased inputs of inorganic material, and intensification of the formation of iron oxyhydroxide crusts (Törnqvist & Joosten 1988, Janssen 1994, Martínez Cortizas & Moares 1995, van der Knaap & van Leeuwen 1995, Pontevedra-Pombal 2002, Carrión *et al.* 2010, Pontevedra-Pombal *et al.* 2013, Castro *et al.* 2015).

Vertical peat accumulation rates are highly variable, depending on the type and location of the peatland. In the Florida Everglades (USA) the rate has been estimated to be  $0.84 \text{ mm yr}^{-1}$  (McDowell *et al.* 1969), while in some ombrotrophic bogs in Canada it has been reported to be  $0.025 \text{ mm yr}^{-1}$  (Boville *et al.* 1982). In raised bogs, mean rates have been calculated to be  $0.56 \text{ mm yr}^{-1}$  in *Carex* communities,  $0.32 \text{ mm yr}^{-1}$  in *Scheuchzeria-Cuspidata* communities and  $0.76 \text{ mm yr}^{-1}$  in *Sphagnum* communities (Mäkilä 1997). Vertical growth rates of  $0.2\text{--}1.5 \text{ mm yr}^{-1}$  (Silvola 1986) and  $0.1\text{--}0.8 \text{ mm yr}^{-1}$  (Ovenden 1990) have been proposed for subarctic and boreal peatlands. For ombrotrophic bogs, mean rates of  $0.40 \text{ mm yr}^{-1}$  (Iceland),  $0.49 \text{ mm yr}^{-1}$  (Estonia),  $0.18 \text{ mm yr}^{-1}$  (Norway) (Everett 1983) and  $0.20\text{--}4.0 \text{ mm yr}^{-1}$  (Finland) (Korhola & Tolonen 1996) have been estimated. For concentric raised bogs, rates of  $0.52 \text{ mm yr}^{-1}$  (Finland) (Mäkilä 1997),  $0.48\text{--}0.50 \text{ mm yr}^{-1}$  (Canada) (Gorham 1991) and  $0.6\text{--}0.8 \text{ mm yr}^{-1}$  (southern zone of the former USSR) (Botch *et al.* 1995) have been reported. On a worldwide scale, Gorham (1991) suggested a value of  $0.5 \text{ mm yr}^{-1}$  as a conservative but reasonable estimate of the vertical peat accumulation rate, and Blackford (2000) proposed a range of  $0.2\text{--}2 \text{ mm yr}^{-1}$ .

The mean vertical peat accumulation rate calculated for Iberian peatlands in the present study was  $0.41 \pm 0.35 \text{ mm yr}^{-1}$ , with higher rates in raised bogs ( $0.47 \pm 0.20 \text{ mm yr}^{-1}$ ) than in blanket bogs ( $0.36 \pm 0.14 \text{ mm yr}^{-1}$ ) and fens ( $0.34 \pm 0.18 \text{ mm yr}^{-1}$ ). If outliers are ignored, more than 90 % of these peatlands display accumulation rates of between  $0.11$  and  $0.90 \text{ mm yr}^{-1}$ , with a mean value of  $0.33 \text{ mm yr}^{-1}$ . The accumulation rates of the Iberian peatlands are, therefore, similar to those determined for peatlands located in more northerly areas, both for peatlands in general and for the different types. No significant differences in the rates were identified in relation to the geographical area, biogeographical region, altitude, or period of the Holocene when peat formation began.

Vertical peat accumulation rates of more than  $1 \text{ mm yr}^{-1}$  ( $1 \text{ cm per decade}$ ) for Iberian mires have been observed only during the peat-forming cycles that have taken place within the last 600 years. This high rate may be attributed to the combined effects of favourable climatic conditions during the LIA (Martínez Cortizas *et al.* 1999), the intensification of deforestation (Pontevedra-Pombal *et al.* 2012), and the apparent decrease in rate of accumulation as the age of the peat increases (Tolonen & Turunen 1996).

## CONCLUSIONS

Based on this study of a group of representative (type and geographical distribution) acid peatlands on the Iberian Peninsula, it can be concluded that their chronologies, peat accumulation rates and formation processes were similar to those of other Atlantic peatlands in Europe. The distribution of these ecosystems is uneven. Fens are more widely represented and distributed throughout the Iberian Peninsula, while bogs are restricted to the N and, mainly, NW of the territory. There are also differences in the times when their formation commenced, which range from the late-glacial to the LIA in the case of fens and are confined to the early and late Holocene for bogs.

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## REFERENCES

- Abel-Schaad, D. & López-Sáez, J.A. (2013) Vegetation changes in relation to fire history and human activities at the Peña Negra mire (Bejar Range, Iberian Central Mountain System, Spain) during the past 4,000 years. *Vegetation History and Archaeobotany*, 22, 199–214.
- Abel-Schaad, D., López-Sáez, J.A. & Pulido, F. (2014) Heathlands, fire and grazing. A



- paleoenvironmental view of Las Hurdes (Cáceres, Spain) history during the last 1200 years. *Forest Systems*, 23, 247–258.
- Andrade, A. (1994) *Dinámica de la Vegetación, Durante los Últimos 3000 BP, en las Sierras de La Paramera, La Serrota y Villafranca (Ávila), a partir del Análisis Polínico (Vegetation Dynamics During the Last 3000 BP, in the Sierras de La Paramera, La Serrota and Villafranca (Ávila), from Pollen Analysis)*. PhD thesis, University of Alcalá de Henares, Madrid, 265 pp. (in Spanish).
- Atienza Ballano, M. (1993) *Evolución del Paisaje Vegetal en las Sierras de Béjar y Francia Durante el Holoceno, a partir del Análisis Palinológico (Evolution of Plant Landscape in the Sierra de Béjar and France During the Holocene, from Palynological Analysis)*. PhD thesis, University of Alcalá de Henares, Madrid, 247 pp. (in Spanish).
- Averdieck, F.R., Hayen, H., Heathwaite, A.L. & Willkomm, H. (1993) The chronology of mire development. In: Heathwaite, A.L. & Göttlich, K. (eds.) *Mires: Process, Exploitation and Conservation*, John Wiley & Sons, Chichester, England, 123–170.
- Bennett, K.D., Boreham, S., Sharp, M.J. & Switsur, V.R. (1992) Holocene history of environment, vegetation and human settlement on Catta Ness, Lunnasting, Shetland. *Journal of Ecology*, 80, 241–273.
- Bindler, R., Renberg, I. & Klaminder, J. (2008) Bridging the gap between ancient metal pollution and contemporary biogeochemistry. *Journal of Paleolimnology*, 40, 755–770.
- Blackford, J. (2000) Palaeoclimatic records from peat bogs. *Tree*, 15, 193–198.
- Blanco-González, A., López-Sáez, J.A. & López-Merino, L. (2009) Ocupación y uso del territorio en el sector centromeridional de la cuenca del Duero entre la antigüedad y la alta edad media (siglos I–XI D.C.) (Occupation and land use in the central southern area of the Duero basin between antiquity and the early Middle Ages (I–XI centuries A.D.)). *Archivo Español de Arqueología*, 82, 275–300 (in Spanish).
- Botch, M.S., Kobak, K.I., Vinson, T.S. & Kolchugina, T.P. (1995) Carbon pools and accumulation in peatlands of the former Soviet Union. *Global Biogeochemical Cycles*, 9, 37–46.
- Boville, B.W., Munn, R.E. & Hare, F.K. (1982) *The Storage of Non-Living Organic Carbon in Boreal and Arctic Zones - Canada, Final Report*. Contract No. DE-AS01-81EV-10688, United States Department of Energy, Washington DC, 89 pp.
- Byrne, K.A., Chojnicki, B., Christensen, T.R., Drösler, M., Freibauer, A., Friberg, T., Frolking, S., Lindroth, A., Mailhammer, J., Malmer, N., Selin, P., Turunen, J., Valentini, R. & Zetterberg, L. (2004) *EU Peatlands: Current Carbon Stocks and Trace Gas Fluxes*. Concerted Action CarboEurope-GHG - Synthesis of the European Greenhouse Gas Budget, Department of Forest Science and Environment, Viterbo, Italy, 58 pp.
- Carrión, J.S., Fernández, S., González-Sampériz, P., Gil-Romera, G., Badal, E., Carrión-Marco, Y., López-Merino, L., López-Sáez, J.A., Fierro, E. & Burjachs, F. (2010) Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands. *Review of Palaeobotany and Palynology*, 162, 458–475.
- Carrión, J.S., Fuentes, N., González-Sampériz, P., Sánchez-Quirante, L., Finlayson, J.C., Fernández, S. & Andrade, A. (2007) Holocene environmental change in a montane region of southern Europe with a long history of human settlement. *Quaternary Science Reviews*, 26, 1455–1475.
- Castro, D., Souto, M., Garcia-Rodeja, E., Pontevedra-Pombal, X. & Fraga, M.I. (2015) Climate change records between the mid- and late Holocene in a peat bog from Serra do Xistral (SW Europe) using plant macrofossils and peat humification analyses. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 420, 82–95.
- Chambers, F.M. (1988) Archaeology and the flora of the British Isles: The moorland experience. In: Jones, M. (ed.) *Archaeology and the Flora of the British Isles*, Oxford University Committee for Archaeology, Oxford, UK, 107–115.
- Chambers, F.M., Daniell, J.R.G. & ACCROTELM Members (2010) Peatland archives of late-Holocene climate change in northern Europe. *PAGES Newsletter*, 18(1), 4–9.
- Cubizolle, H., Tourman, A., Argant, J., Porteret, J., Oberlin, C. & Serreyssol, K. (2003) Origins of European biodiversity: palaeo-geographic signification of peat inception during the Holocene in the granitic eastern Massif Central (France). *Landscape Ecology*, 18, 227–238.
- Dorado-Valiño, M., López-Sáez, J.A. & García-Gómez, E. (2014a) Contributions to the European pollen database: 21. Patateros, Toledo Mountains (central Spain). *Grana*, 53, 171–173.
- Dorado-Valiño, M., López-Sáez, J.A. & García-Gómez, E. (2014b) Contributions to the European pollen database: 26. Valdeyernos, Toledo Mountains (central Spain). *Grana*, 53, 315–317.
- Dupré-Ollivier, M., Pérez-Obiol, R. & Roure, J.M. (1994) Análisis polínico del sondeo TU de la

- turbera de Torreblanca (Castellón, España) (Pollen analysis of the TU core from Torreblanca peatland (Castellón, Spain). In: Dupré-Ollivier, M., Burgaz Moreno, M.E., Mateu Andrés, I. & Güemes, J. (eds.) *Trabajos de Palinología Básica y Aplicada: X Simposio de Palinología (Works in Basic and Applied Palynology: X Symposium of Palynology)*, A.P.L.E., University of Valencia, Valencia, Spain, 165–174 (in Spanish).
- Ejarque, A., Julià, R., Riera, S., Palet, J.M., Orengo, H.A., Miras, Y. & Gascón, C. (2009) Tracing the history of highland human management in the eastern Pre-Pyrenees: an interdisciplinary palaeoenvironmental study at the Pradell fen, Spain. *The Holocene*, 19, 1241–1255.
- Ejarque, A., Miras, Y., Riera, S., Palet, J.M. & Orengo, H.A. (2010) Testing microregional variability in the Holocene shaping of high mountain cultural landscapes: a palaeo-environmental case-study in the eastern Pyrenees. *Journal of Archaeological Science*, 37, 1468–1479.
- Erhart, H. (1951) *La Genèse des Sols en tant que Phénomène Géologique. Esquisse d'une Théorie Géologique et Géochimique. Biostasie et Rhéxistatie (The Genesis of Soils as a Geological Phenomenon. Sketch of a Geological and Geochemical Theory. Biostaxia and Resistaxia)*. Masson, Paris, 90 pp. (in French).
- European Commission (2016) Natura 2000 web pages. Online at: <http://ec.europa.eu/environment/nature/natura2000/>
- Evans, D. (2006) The habitats of the European Union Habitats Directive. *Biology and Environment: Proceedings of the Royal Irish Academy*, 106B, 167–173.
- Evans, M., Warburton, J. & Yang, J. (2006) Eroding blanket peat catchments: Global and local implications of upland organic sediment budgets. *Geomorphology*, 79, 45–57.
- Everett, K.R. (1983) Histosols. In: Wilding, L.P., Smeck, N.E. & Hall, G.F. (eds.) *Pedogenesis and Soil Taxonomy. II. The Soil Orders*, Elsevier Science, Amsterdam, The Netherlands, 1–53.
- Franco-Múgica, F. (1995) *Estudio Palinológico de Turberas Holocenas en el Sistema Central: Reconstrucción Paisajística y Acción Antrópica (Palynological Study of Holocene Peatlands in the Central System: Landscape Reconstruction and Anthropic Activity)*. PhD thesis, Universidad Autónoma, Madrid, 382 pp. (in Spanish).
- Franco-Múgica, F., García-Antón, M. & Sainz-Ollero, H. (1997) Impacto antrópico y dinámica de la vegetación durante los últimos 2000 años BP en la vertiente septentrional de la Sierra de Gredos: Navarredonda (Ávila, España) (Anthropic impact and vegetation dynamics during the last 2000 years BP on the northern slope of the Sierra de Gredos: Navarredonda (Ávila, Spain)). *Revue de Paléobiologie*, 16, 29–45 (in Spanish).
- Franco-Múgica, F., García-Antón, M. & Sainz-Ollero, H. (1998) Vegetation dynamics and human impact in the Sierra de Guadarrama, Central System, Spain. *The Holocene*, 8, 69–82.
- Franco-Múgica, F., García-Antón, M., Maldonado, J., Morla, C. & Sainz-Ollero, H. (2001) Evolución de la vegetación en el sector septentrional del macizo de Ayllón, (Sistema Central). Análisis polínico de la turbera de Pelagallinas (Evolution of vegetation in the northern sector of the Ayllón massif (Central System). Pollen analysis of the Pelagallinas peatland). *Anales del Jardín Botánico de Madrid*, 59, 113–124 (in Spanish).
- Freeman, C., Ostle, N. & Kang, H. (2001) An enzymic 'latch' on a global carbon store. *Nature*, 409, 149.
- Gallego-Sala, A.V., Charman, D.J., Harrison, S.P., Li, G. & Prentice, I.C. (2015) Climate-driven expansion of blanket bogs in Britain during the Holocene. *Climate of the Past Discussions*, 11, 4811–4832.
- Galop, D., Tual, M., Monna, F., Dominik, J., Beyrie, A. & Marembert, F. (2001) Cinq millénaires de métallurgie en montagne basque. Les apports d'une démarche intégrée alliant palynologie et géochimie isotopique du plomb (Five millennia of metallurgy in the Basque mountains. The contributions of an integrated approach combining palynology and lead isotope geochemistry). *Sud-Ouest Européen (South-West European)*, 11, 3–15, Presses Universitaires du Mirail (PUM) (Mirail University Press), Toulouse, eISSN 2273-0257 (in French).
- Galop, D., Carozza, L., Marembert, F. & Bal, M.C. (2004) Activités agropastorales et climat durant l'Âge du Bronze dans les Pyrénées: l'état de la question à la lumière des données environnementales et archéologiques (Agropastoral activity and climate during the Bronze Age in the Pyrenees: the state of knowledge based on environmental and archaeological data). In: *Eclipse 2 "emprises et déprises agricoles, expansion et régression des sociétés entre 3500 et 2500 BP ("agricultural gains and losses, expansion and regression of companies between 3500 and 2500 BP)*, CTHS, 21 (archived documents), 107–119, Congrès des Sociétés Historiques et Scientifiques, Besançon, France (in French).
- García-Antón, M., Ruiz Zapata, B. & Ugarte, F.M.<sup>a</sup>. (1989) Análisis geomorfológico y palinológico de

- la turbera de Saldropo (Barazar. Zeanuri/Bizkaia) (Geomorphological and palynological analysis of the Saldropo peatland (Barazar. Zeanuri/Bizkaia). *Lurralde*, 12, 25–44, ISSN 1697-3070 (in Spanish).
- García-Antón, M., Franco-Múgica, F., Maldonado, J., Morla-Juaristi, C. & Sainz-Ollero, H. (1997) New data concerning the evolution of the vegetation in Lillo pinewood (Leon, Spain). *Journal of Biogeography*, 26, 929–934.
- García-Antón, M., Franco-Múgica, F., Morla-Juaristi, C. & Maldonado-Ruiz, J. (2011) The biogeographical role of *Pinus* forest on the Northern Spanish Meseta: a new Holocene sequence. *Quaternary Science Reviews*, 30, 757–768.
- Gil García, M.J., Tomás las Heras, R. & Ruiz Zapata, M.B. (1995) Degradación antropogénica de la vegetación, en base al análisis polínico, en la Sierra de Guadarrama: Altos de Hontanar (Madrid) (Anthropic degradation of vegetation, based on pollen analysis, in the Sierra de Guadarrama: Altos de Hontanar (Madrid)). *Lazaroa*, 15, 151–163, ISSN 0210-9778, Universidad Complutense de Madrid (in Spanish).
- Gil García, M.J., Tomás Las Heras, R., Núñez Olivera, E. & Martínez Abaigar, J. (1996) Acción humana sobre el medio natural en la Sierra de Cameros a partir del análisis polínico (Human impact on the natural environment in the Sierra de Cameros from pollen analysis). *ZUBÍA Monográfico*, 8, 29–42, Instituto Estudios Riojanos, Logroño, ISSN 0213-4306 (in Spanish).
- Gil García, M.J., Ruiz Zapata, M.B., Dorado, M. & Valdeolmillos, A. (2001) Paisaje vegetal durante el Holoceno en una secuencia de la Sierra de Cebollera (Trampal de Nieva. La Rioja, España) (Vegetation landscape during the Holocene in a sequence from the Sierra de Cebollera (Trampal de Nieva. La Rioja, Spain). *Actas XIII Simposio de la Asociación de Palinólogos en Lengua Española*, Cartagena, 415–422 (in Spanish).
- Gil García, M.J., Dorado-Valiño, M., Valdeolmillos Rodríguez, A. & Ruiz Zapata, M.B. (2002) Late-glacial and Holocene paleoclimatic record from Sierra de Cebollera (northern Iberian range, Spain). *Quaternary International*, 93–94, 13–18.
- Gil-Romera, G., García Antón, M. & Calleja, J.A. (2008) The late Holocene palaeoecological sequence of Serranía de las Villuercas (southern Meseta, western Spain). *Vegetation History and Archaeobotany*, 17, 653–666.
- Gómez-Lobo, A. (1993) *Historia de la Vegetación Durante los Últimos 15000 Años en los Picos de Urbión (Soria) en Base al Análisis Polínico (History of Vegetation Over the Last 15,000 Years in the Picos de Urbión (Soria) Based on Pollen Analysis)*. PhD thesis, University of Alcalá de Henares, Madrid.
- González-Sampériz, P., Valero-Garcés, B., Moreno, A., Jalut, G., García-Ruiz, J., Martí-Bono, C., Delgado-Huertas, A., Navas, A., Otto, T. & Dedoubat, J.J. (2006) Climate variability in the Spanish Pyrenees during the last 30,000 yr revealed by the El Portalet sequence. *Quaternary Research*, 66, 38–52.
- Gorham, E. & Janssens, J.A. (1992) The paleorecord of geochemistry and hydrology in northern peatlands and its relation to global change. *Suo*, 43, 9–19.
- Gorham, E. (1991) Northern peatlands: role in the carbon cycle and probable responses to climatic warming. *Ecological Applications*, 1, 182–195.
- Gorham, E., Lehman, C., Dyke, A., Janssens, J. & Dyke, L. (2007) Temporal and spatial aspects of peatland initiation following deglaciation in North America. *Quaternary Science Reviews*, 26, 300–311.
- Heras, P., Infante, M., Pontevedra-Pombal, X. & Nóvoa-Muñoz, J.C. (2017) Mires and peatlands of Spain. In: Joosten, H., Tanneberger, F. & Moen, A. (eds.) *Mires and Peatlands of Europe: Status, Distribution and Conservation*. Schweizerbart Science Publishers, Stuttgart, 639–656.
- Huang, C.C. (2002) Holocene landscape development and human impact in the Connemara Uplands, Western Ireland. *Journal of Biogeography*, 29, 153–165.
- Hughes, P.D.M. & Barber, K.E. (2003) Mire development across the fen–bog transition on the Teifi floodplain at Tregaron Bog, Ceredigion, Wales, and a comparison with 13 other raised bogs. *Journal of Ecology*, 91, 253–264.
- Janssen, C.R. (1994) Palynological indications for the extent of the impact of man during Roman times in the western part of the Iberian Peninsula. In: Frenzel, B. (ed.) *Evaluation of Land Surfaces Cleared from Forest in the Mediterranean Region During the Time of the Roman Empire*, Palaeoclimate Research, Gustav Fischer, Stuttgart, 15–22.
- Janssen, C.R. & Woldringh, R.E. (1981) A preliminary radiocarbon dated pollen sequence from the Serra da Estrela, Portugal. *Finisterra*, XVI(32), 299–309.
- Jiménez Ballesta, R., López Martínez, J., López García, P. & Ibañez, J.J. (1985) Contribución al conocimiento de las formaciones superficiales turbosas en las Sierras de Guadarrama y Ayllón. Análisis polínicos (Contribution on the superficial peat formations in the Sierras de Guadarrama and

- Ayllón). *Actas I Reunión del Cuaternario Ibérico (Lisboa)*, 2, 213–224 (in Spanish).
- Joosten, H. & Clarke, D. (2002) *Wise Use of Mires and Peatlands: Background and Principles Including a Framework for Decision-making*. International Mire Conservation Group and International Peat Society, Jyväskylä, 304 pp.
- Korhola, A. & Tolonen, K. (1996) The natural history of mires in Finland and the rate of peat accumulation. In: Vasander, H. (ed.) *Peatlands in Finland*, Finnish Peatland Society, Helsinki, 20–26.
- Laine, J., Silvola, J., Tolonen, K., Alm, J., Nykänen, H., Vasander, H., Sallantausta, T., Savolainen, I., Sinisalo, J. & Martikainen, P.J. (1996) Effect of water-level drawdown on global climatic warming: northern peatlands. *Ambio*, 25, 179–184.
- Limpens, J., Berendse, F., Blodau, C., Canadell, J.G., Freeman, C., Holden, J., Roulet, N., Rydin, H. & Schaepman-Strub, G. (2008) Peatlands and the carbon cycle: from local processes to global implications - a synthesis. *Biogeosciences*, 5, 1475–1491.
- Loisel, J., Yu, Z., Beilman, D.W., Camill, P., Alm, J., Amesbury, M.J., Anderson, D., Andersson, S., Bochicchio, C., Barber, K.E., Belyea, L.R., Bunbury, J., Chambers, F.M., Charman, D.J., De Vleeschouwer, F., Fiałkiewicz-Kozieł, B., Finkelstein, S.A., Gałka, M., Garneau, M., Hammarlund, D., Hinchcliffe, W., Holmquist, J., Hughes, P.D.M., Jones, M.C., Klein, E.S., Kokfelt, U., Korhola, A., Kuhry, P., Lamarre, A., Lamentowicz, M., Large, D., Lavoie, M., MacDonald, G., Magnan, G., Makila, M., Mallon, G., Mathijssen, P., Mauquoy, D., McCarroll, J., Moore, T.R., Nichols, J., O'Reilly, B., Oksanen, P., Packalen, M., Peteet, D., Richard, P.J.H., Robinson, S., Ronkainen, T., Rundgren, M., Sannel, A.B.K., Tarnocai, C., Thom, T., Tuittila, E.-S., Turetsky, M., Valiranta, M., van der Linden, M., van Geel, B., van Bellen, S., Vitt, D., Zhao, Y. & Zhou, W. (2014) A database and synthesis of northern peatland soil properties and Holocene carbon and nitrogen accumulation. *The Holocene*, 24, 1028–1042.
- López-Días, V., Borrego, A.G., Blanco, C.G., Arboleya, M., López-Sáez, J.A. & López-Merino, L. (2010) Biomarkers in a peat deposit in Northern Spain (Huelga de Bayas, Asturias) as proxy for climate variation. *Journal of Chromatography A*, 1217, 3538–3546.
- López-Merino, L., López-Sáez, J.A., Alba-Sánchez, F., Pérez-Díaz, S. & Carrión, J.S. (2009) 2000 years of pastoralism and fire shaping high-altitude vegetation of Sierra de Gredos in central Spain. *Review of Palaeobotany and Palynology*, 158, 42–51.
- López-Merino, L., Martínez Cortizas, A. & López-Sáez, J.A. (2010) Early agriculture and palaeoenvironmental history in the North of the Iberian Peninsula: a multi-proxy analysis of the Monte Areo mire (Asturias, Spain). *Journal of Archaeological Science*, 37, 1978–1988.
- López-Sáez, J.A., López-Merino, L., Alba-Sánchez, F., Pérez-Díaz, S., Abel-Schaad, D. & Carrión, J.S. (2010) Late Holocene ecological history of *Pinus pinaster* forests in the Sierra de Gredos of central Spain. *Plant Ecology*, 206, 195–209.
- López-Sáez, J.A., Abel-Schaad, D., Alba-Sánchez, F., González-Pellejero, R., Frochoso, M. & Allende, F. (2013) Culazón, Cantabrian Mountains (northern Spain). *Grana*, 52, 316–318.
- López-Sáez, J.A., Alba Sánchez, F., Robles López, S., Pérez Díaz, S., Abel Schaad, D., Sabariego Ruiz, S. & Glais, A. (2016) Exploring seven hundred years of transhumance, climate dynamic, fire and human activity through a historical mountain pass in central Spain. *Journal of Mountain Science*, 13, 1139–1153.
- MacDonald, G.M., Beilman, D.W., Kremenetski, K.V., Sheng, Y., Smith, L.C. & Velichko, A.A. (2006) Rapid early development of circumarctic peatlands and atmospheric CH<sub>4</sub> and CO<sub>2</sub> variations. *Science*, 314, 285–288.
- Magny, M. (1995) *Une Histoire du Climat. Des Derniers Mammouths au Siècle de L'automobile (A History of the Climate. The Last Mammoths to the Century of the Automobile)*. Éditions Errance, Paris, 176 pp. (in French).
- Mäkilä, M. (1997) Holocene lateral expansion, peat growth and carbon accumulation on Haukasuo, a raised bog in southeastern Finland. *Boreas*, 26, 1–14.
- Malmer, N. (1975) Development of bog mires. In: Hassler, A.D. (ed.) *Coupling of Land and Water Systems*. Ecological Studies 10, Springer-Verlag, New York, 85–92.
- Maltby, E. & Proctor, M.C.F. (1996) Peatlands: their nature and role in the biosphere. In: Lappalainen, E. (ed.) *Global Peat Resources*. International Peat Society, Jyväskylä, Finland. 366 pp.
- Mariscal, B. (1993) Variación de la vegetación holocena (4300–280 BP) de Cantabria a través del análisis polínico de la turbera de Alsa (Variation in the Holocene vegetation (4300–280 BP) of Cantabria through pollen analysis of Alsa peatland). *Estudios Geológicos*, 49, 63–68 (in Spanish).
- Martínez Cortizas, A. & Moares, C. (1995) *Edafología y Arqueología: Estudio de*

- Yacimientos Arqueológicos al Aire Libre en Galicia (Soil Science and Archaeology: Studying Open-air Archaeological Sites in Galicia)*. Consellería de Cultura, Xunta de Galicia, Santiago de Compostela, 199 pp. (in Spanish).
- Martínez Cortizas, A., Pontevedra-Pombal, X., Nóvoa-Muñoz, J.C., García-Rodeja, E. & Shotyk, W. (1999) Mercury in a Spanish peat bog: archive of climate change and atmospheric metal deposition. *Science*, 284, 939–942.
- Martínez Cortizas, A., López-Merino, L., Bindler, R., Mighall, T. & Kylander, M.E. (2016) Early atmospheric metal pollution provides evidence for Chalcolithic/Bronze Age mining and metallurgy in Southwestern Europe. *Science of the Total Environment*, 545–546, 398–406.
- Mateus, J.E. (1989) Lagoa Travessa: a Holocene pollen diagram from the south-west coast of Portugal. *Revista de Biologia*, 14, 17–94.
- McDowell, L.L., Stephens, J.C. & Stewart, E.H. (1969) Radiocarbon chronology of the Florida everglades peat. *Soil Science Society of America Proceedings*, 33, 743–745.
- Melendez, B. & Fuster, J. (2003) *Geología* (Geology). Paraninfo Editores, Madrid, 911 pp. (in Spanish).
- Menéndez Amor, J. (1968) Estudio espora-polínico de una turbera en el Valle de la Nava (provincia de Burgos) (Spore-palynological study of a peatland in the Valle de la Nava (Burgos Province). *Boletín de la Real Sociedad Española de Historia Natural (Geología)*, 66, 35–39 (in Spanish).
- Menéndez Amor, J. (1971) Estudio espora-polínico de dos turberas en la Sierra de Queija (Orense) (Spore-palynological study of two peatlands in the Sierra de Queixa (Ourense)). *Boletín de la Real Sociedad Española de Historia Natural (Geología)*, 69, 85–92 (in Spanish).
- Menéndez Amor, J. & Florschütz, F. (1961) Contribución al conocimiento de la historia de la vegetación en España durante el Cuaternario. Resultado del análisis paliológico de algunas series de muestras de turba, arcilla y otros sedimentos recogidos en los alrededores de: I. Puebla de Sanabria (Zamora); II. Buelna (Asturias); Viveiro (Galicia) y el Levante (Contribution on the vegetation history of Spain during the Quaternary. Palynological analysis results for some series of samples of peat, clay and other sediments collected around: I. Puebla de Sanabria (Zamora); II. Buelna (Asturias); Viveiro (Galicia) and the Levante). *Estudios Geológicos*, XVII, 83–99 (in Spanish).
- Miras, Y., Ejarque, A., Riera, S., Palet, J.M., Orenge, H. & Euba, I. (2007) Dynamique holocène de la végétation et occupation des Pyrénées andorranes depuis le Néolithique ancien d'après l'analyse pollinique de la tourbière de Bosc dels Estanyons (2180 m, Vall del Madriu, Andorre) (Holocene dynamics of vegetation and occupation of the Andorran Pyrenees since the Early Neolithic according to pollen analysis of the peatland Bosc dels Estanyons (2180 m, Vall del Madriu, Andorra). *Comptes Rendus de l'Académie des Sciences Paris, Palévol*, 6, 291–300 (in French).
- Mitchell, G.F. (1972) Soil deterioration associated with prehistoric agriculture in Ireland. In: *Proceedings of the 24<sup>th</sup> International Geological Congress Symposium 1: Earth Sciences and the Quality of Life*, International Union of Geological Sciences (IUGS), Montréal, Canada, 59–68.
- Moore, P.D., Merryfield, D.L. & Price, M.D.R. (1984) The vegetation and development of blanket mires. In: Moore, P.D. (ed.) *European Mires*, Academic Press, London, 203–235.
- Morales-Molino, C. & García-Antón, M. (2014) Vegetation and fire history since the last glacial maximum in an inland area of the western Mediterranean Basin (Northern Iberian Plateau, NW Spain). *Quaternary Research*, 81, 63–77.
- Morales-Molino, C., García-Antón, M. & Morla, C. (2011) Late Holocene vegetation dynamics on an Atlantic–Mediterranean mountain in NW Iberia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 302, 323–337.
- Morales-Molino, C., García-Antón, M., Postigo-Mijarra, J.M. & Morla, C. (2013) Holocene vegetation, fire and climate interactions on the westernmost fringe of the Mediterranean Basin. *Quaternary Science Reviews*, 59, 5–17.
- Moreno, L., Gallego, J.L.R., Ortiz, J.E., Torres, T. & Sierra, C. (2009) Distribución de elementos traza en el registro de la Turbera de Roñanzas (Asturias, España) (Distribution of trace elements in the record of the Roñanzas peatland (Asturias, Spain). *Geogaceta*, 46, 123–126 (in Spanish).
- Muñoz Sobrino, C. (2001) *Cambio Climático y Dinámica del Paisaje en las Montañas del Noroeste de la Península Ibérica (Climate Change and Landscape Dynamics in the Mountains of the Northwest Iberian Peninsula)*. PhD thesis, University of Santiago de Compostela, 163 pp. (in Spanish).
- Muñoz Sobrino, C., Ramil-Rego, P. & Rodríguez Guitián, M.A. (2001) Vegetation in the mountains of northwest Iberia during the last glacial-interglacial transition. *Vegetation History and Archaeobotany*, 10, 7–21.
- Muñoz Sobrino, C., Ramil-Rego, P. & Gómez-Orellana, L. (2004) Vegetation of the Lago de

- Sanabria area (NW Iberia) since the end of the Pleistocene: a palaeoecological reconstruction on the basis of two new pollen sequences. *Vegetation History and Archaeobotany*, 13, 1–22.
- Muñoz Sobrino, C., Suárez-Pérez, F.J., Nava-Fernández, H.S., Fernández-Casado, M.A., Gómez-Orellana, L., Rodríguez, M.A., Fernández-Prieto, J.A. & Ramil-Rego, P. (2012) Environmental changes in the westernmost Cantabrian Range during the postglacial period: the Pena Velosa (Muniellos, Asturias) pollen record. In: Campar, A., Bettencourt, A.M.S., Moura, D., Monteiro-Rodrigues, S. & Caetano, M. I. (eds.) *Environmental Changes and Human Interaction along the Western Atlantic Edge*, Associação Portuguesa para o Estudo do Quaternário, Coimbra, 79–94.
- Ortiz, J.E., Borrego, A.G., Gallego, J.L.R., Sánchez-Palencia, Y., Urbanczyk, J., Torres, T., Domingo, L. & Estébanez, B. (2016) Biomarkers and inorganic proxies in the paleoenvironmental reconstruction of mires: the importance of landscape in Las Conchas (Asturias, Northern Spain). *Organic Geochemistry*, 95, 41–54.
- Ovenden, L. (1990) Peat accumulation in northern wetlands. *Quaternary Research*, 33, 377–386.
- Peiteado-Varela, E. (2017) *Contaminación Atmosférica por Pb en Galicia Mediante el Estudio de su Deposición en Turberas Ombrotroficas: Evolución Temporal y Espacial (Atmospheric Pollution by Pb in Galicia by Studying the Deposition in Ombrotrophic Peatlands: Temporal and Spatial Evolution)*. Unpublished PhD thesis, University of Santiago de Compostela (in Spanish).
- Pélachs, A., Soriano, J.M., Nadal, J. & Esteban, A. (2007) Holocene environmental history and human impact in the Pyrenees. *Contributions to Science*, 3, 421–429.
- Peñalba, M.C. (1994) The history of the Holocene vegetation in northern Spain from pollen analysis. *Journal of Ecology*, 82, 815–832.
- Pérez Díaz, S., López Sáez, J.A., Pontevedra-Pombal, X., Souto-Souto, M. & Galop, D. (2016) 8000 years of vegetation history in northern Iberian Peninsula inferred from the palaeo-environmental study of the Zalama ombrotrophic bog (Basque-Cantabrian Mountains, Spain). *Boreas*, 45, 658–672.
- Pérez-Obiol, R., García-Codron, J.C., Pélachs, A., Pérez-Haase, A. & Soriano, J.M. (2016) Landscape dynamics and fire activity since 6740 cal yr BP in the Cantabrian region (La Molina peat bog, Puente Viesgo, Spain). *Quaternary Science Reviews*, 135, 65–78.
- Pontevedra-Pombal, X. (2002) *Turberas de Montaña de Galicia. Génesis, Propiedades y su Aplicación como Registros Ambientales Geoquímicos (Mountain Mires of Galicia. Genesis, Properties and their Use as Geochemical Environmental Records)*. PhD thesis, first edition, University of Santiago de Compostela Editorial, Santiago de Compostela, Spain, 489 pp. (in Spanish).
- Pontevedra-Pombal, X., Nóvoa-Muñoz, J.C., García-Rodeja, E. & Martínez Cortizas, A. (2006) Mountain mires from Galicia (NW Spain). In: Martini, I.P., Martínez, A. & Chesworth, W. (eds.) *Peatlands: Evolution and Records of Environmental and Climate Changes*, Developments in Earth Surface Processes Volume 9, Elsevier, London, 83–108.
- Pontevedra-Pombal, X., Rey-Salgueiro, L., García-Falcón, M.S., Martínez-Carballo, E., Simal-Gándara, J. & Martínez Cortizas, A. (2012) Pre-industrial accumulation of anthropogenic polycyclic aromatic hydrocarbons found in a blanket bog of the Iberian Peninsula. *Environmental Research*, 116, 36–43.
- Pontevedra-Pombal, X., Mighall, T.M., Nóvoa-Muñoz, J.C., Peiteado-Varela, E., Rodríguez-Racedo, J., García-Rodeja, E. & Martínez Cortizas, A. (2013) Five thousand years of atmospheric Ni, Zn, As, and Cd deposition recorded in bogs from NW Iberia: prehistoric and historic anthropogenic contributions. *Journal of Archaeological Science*, 40, 764–777.
- Raeymaekers, G. (1999) *Conserving Mires in the European Union*. LIFE-Nature Office for Official Publications of the European Communities, Luxembourg, 96 pp.
- Ramil-Rego, P. (1992) La vegetación cuaternaria de las sierras septentrionales de Lugo a través del análisis polínico (Quaternary vegetation of the northern mountains of Lugo according to pollen analysis). PhD thesis, University of Santiago de Compostela, 356 pp. (in Spanish).
- Ramil-Rego, P. & Aira Rodríguez, M.J. (1993a) Estudio palinológico de la turbera do Río das Furnas, Lugo (Palynological study of the Río das Furnas peatland, Lugo). *Anales de la Asociación de Palinología en Lengua Española*, 6, 83–92 (in Spanish).
- Ramil-Rego, P. & Aira Rodríguez, M.J. (1993b) Estudio palinológico de la turbera de Sever (Lugo) (Palynological study of the Sever peatland (Lugo)). *Acta Botanica Malacitana*, 18, 125–133 (in Spanish).
- Ramil-Rego, P. & Aira Rodríguez, M.J. (1994) Estudio palinológico de la turbera de Schwejk, Lugo (Palynological study of Schwejk peatland,



- Lugo). *Studia Botánica*, 12, 259–269.
- Ramil-Rego, P., Taboada Castro, M.T. & Aira Rodríguez, M.J. (1993) Estudio palinológico y factores de formación de la turbera de Gañidoira (Lugo, España) (Palynological study and formation factors of the Gañidoira peatland (Lugo, Spain)). In: Fumanal, M.P. & Bernabeu, J. (eds.) *Estudios Sobre Cuaternario (Quaternary Studies)*, Transactions of the VIII National Quaternary Conference, Asociación Española para el Estudio del Cuaternario / Universitat de València, Valencia, 191–197 (in Spanish).
- Ramil-Rego, P., Aira Rodríguez, M.J. & Taboada Castro, M.T. (1994) Análisis polínico y sedimentológico de dos turberas en las sierras septentrionales de Galicia (NO de España) (Pollen and sedimentological analysis of two peatlands in the northern mountains of Galicia (NW Spain)). *Revue de Paléobiologie*, 13, 9–28 (in Spanish).
- Ruiz Zapata, M.B. & Acaso Deltell, E. (1981) Contribución al estudio del cuadro vegetal y climático durante el Cuaternario reciente en el Macizo Central de Gredos (Ávila) (Contribution on the vegetation and climate picture during the recent Quaternary in the Massif Central of Gredos (Ávila)). *Boletín de la Real Sociedad Española de Historia Natural*, 79, 299–307.
- Ruiz Zapata, M.B., Jiménez Sánchez, M., Farias Arquer, P., Gil García, M.J., Dorado-Valiño, M. & Valdeolmillos Rodríguez, A. (2002) Registro palinológico de un depósito holoceno del Parque Natural de Redes (Cordillera Cantábrica) (Palaeontological record of a Holocene deposit in Redes Natural Park (Cordillera Cantábrica)). In: Moreno Grau, S., Elvira Rendueles, B. & Moreno Angosto, J.M. (eds.) *Libro de Textos Completos*, XIII Simposio de la Asociación de Palinólogos en Lengua Española (APLE), Universidad Politécnica de Cartagena, Cartagena, 391–400 (in Spanish).
- Ruppel, M., Välranta, M., Virtanen, T. & Korhola, A. (2013) Postglacial spatiotemporal peatland initiation and lateral expansion dynamics in North America and northern Europe. *The Holocene*, 23, 1596–1606.
- Sánchez-Goñi, M.F. & Hannon, G. (1999) High-altitude vegetational pattern on the Iberian Mountain Chain (north-central Spain) during the Holocene. *The Holocene*, 9, 39–57.
- Santos, L. (2004) Late Holocene forest history and deforestation dynamics in the Queixa Sierra, Galicia, Northwestern Iberian Peninsula. *Mountain Research and Development*, 24, 251–257.
- Sá-Otero, M.P., Díaz Losada, E. & González Porto, A.V. (2005) A study of the post-glacial vegetation in “Montes do Buio” (NW Spain). *Lagascalía*, 25, 91–114.
- Silva-Sánchez, N., Martínez Cortizas, A., Abel-Schaad, D., López-Sáez, J.A. & Mighall, T.M. (2016) Influence of climate change and human activities on the organic and inorganic composition of peat during the ‘Little Ice Age’ (El Payo mire, W Spain). *The Holocene*, 26, 1290–1303.
- Silva-Sánchez, N., Martínez Cortizas, A. & López-Merino, L. (2014) Linking forest cover, soil erosion and mire hydrology to late-Holocene human activity and climate in NW Spain. *The Holocene*, 24, 714–725.
- Silvola, U. (1986) Carbon dioxide dynamics in mires reclaimed for forestry in eastern Finland. *Annales Botanici Fennici*, 23, 59–67.
- Sjörs, H. (1982) The zonation of northern peatlands and their importance for the carbon balance of the atmosphere. In: Gopal, B., Turner, R.E., Wetzel, R.G. & Whigham, D.F. (eds.) *Wetlands: Ecology and Management*, Proceedings of the First International Wetlands Conference (1980), National Institute of Ecology and International Scientific Publications, Jaipur, India, 11–14.
- Stevenson, A.C. (1985) Studies in the vegetational history of S.W. Spain. II. Palynological investigations at Laguna de las Madres, Huelva. *Journal of Biogeography*, 12, 293–314.
- Stevenson, A.C. (2000) The Holocene forest history of the Montes Universales, Teruel, Spain. *The Holocene*, 10, 603–610.
- Stevenson, A.C. & Moore, P.D. (1988) Studies in the vegetational history of S.W. Spain. IV. Palynological investigations at El Acebrón, Huelva. *Journal of Biogeography*, 15, 339–361.
- Stuiver, M., Reimer, P.J. & Reimer, R.W. (2015) CALIB Radiocarbon Calibration, Version 7.1, computer program for 715 radiocarbon calibration. Online at: <http://calib.qub.ac.uk/calib/>, accessed 20 Oct 2017.
- Taboada Castro, M.T., Aira Rodríguez, M.J. & Díaz-Fierros Viqueira, F. (1993) Formación de turberas en la Sierra de O Bocelo. Relación con las condiciones paleoambientales del holoceno (Genesis of peatlands in the Sierra de O Bocelo. Relationship with Holocene palaeoenvironmental conditions). *Cuaderno Laboratorio Xeolóxico de Laxe*, 18, 365–377 (in Spanish).
- Taylor, J.A. (1983) The peatlands of Great Britain and Ireland. In: Gore, A.J.P. (ed.) *Ecosystems of the World, 4B, Mires: Swamp, Bog, Fen and Moor, Regional Studies*. Elsevier Scientific Publishing Company, Amsterdam, 1–46.
- Telford, R.J., Geegaard, E. & Birks, H.J.B. (2004)

- The intercept is a poor estimate of a calibrated radiocarbon age. *The Holocene*, 14, 296–298.
- Tipping, R. (2008) Blanket peat in the Scottish Highlands: timing, cause, spread and the myth of environmental determinism. *Biodiversity and Conservation*, 17, 2097–2113.
- Tolonen, K. & Turunen, J. (1996) Accumulation rates of carbon in Finland and implications for climate change. *The Holocene*, 6, 171–178.
- Törnqvist, T.E. & Joosten, J.H.J. (1988) On the origin and development of a Subatlantic “man-made” mire in Galicia (northwest Spain). *Proceedings of the 8th International Peat Congress*, International Peat Society, Leningrad, 1, 214–224.
- van der Knaap, W.O. & van Leeuwen, J.F.N. (1995) Holocene vegetation succession and degradation as responses to climatic change and human activity in the Serra de Estrela, Portugal. *Review of Palaeobotany and Palynology*, 89, 153–211.
- Van Mourik, J.M. (1986) *Pollen Profiles of Slope Deposits in the Galician Area (NW Spain)*. Netherlands Geographical Studies 12, Koninklijk Nederlands Aardrijkskundig Genootschap / Fysisch Geografisch en Bodemkundig Laboratorium van de Universiteit van Amsterdam, Amsterdam, 171 pp.
- Vera, J.A. (ed.) (2004) *Geología de España (Geology of Spain)*. SGE-IGME (Sociedad Geológica de España - Instituto Geológico y Minero de España), Madrid, 890 pp. (in Spanish).
- Von Engelbrechten, S. (1998) *Late-glacial and Holocene Vegetation and Environmental History of the Sierra de Urbiión, North-Central Spain*. PhD thesis, Trinity College Dublin, Ireland, 223 pp.
- Walker, M.J.C., Berkelhammer, M., Björck, S., Cwynar, L.C., Fisher, D.A., Long, A.J., Lowe, J.J., Newnham, R.M., Rasmussen, S.O. & Weiss, H. (2012) Formal subdivision of the Holocene series/epoch: a discussion paper by a working group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy). *Journal of Quaternary Science*, 27, 649–659.
- Yu, Z., Loisel, J., Brosseau, D.P., Beilman, D.W. & Hunt, S.J. (2010) Global peatland dynamics since the Last Glacial Maximum. *Geophysical Research Letters*, 37, L1340, 1–5.

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Author for correspondence:

Dr Xabier Pontevedra-Pombal, Group of Environmental Studies Applied to the Natural and Cultural Heritage (GEMAP), Department of Soil Science and Agricultural Chemistry, Faculty of Biology, University of Santiago de Compostela, Campus Vida, 15782 Santiago de Compostela, Galicia, Spain.

Tel: + 34-981563100 ext. 13238; Fax: + 34-881813195; E-mail: xabier.pombal@usc.es

**Appendix:** List and brief details of peatlands on the Iberian Peninsula that were considered in this study (see also Figure 1).

Number	Peatland	Type	Sector	N2000 Network Bioclimatic Zone	Altitude (m a.s.l.)	Reference
1	CHAO DE VEIGA MOL	Raised bog	Serras Septentrionais	Atlantic	695	Present study
2	TREMOAL DE CHAO DE LAMOSO	Blanket bog	Serras Septentrionais	Atlantic	1039	Ramil-Rego <i>et al.</i> 1994
3	TREMOAL DE PENIDO VELLO	Blanket bog	Serras Septentrionais	Atlantic	793	Pontevedra-Pombal 2002
4	TREMOAL DE PENA DA CADELA	Blanket bog	Serras Septentrionais	Atlantic	972	Pontevedra-Pombal <i>et al.</i> 2013
5	CHARCA DE CHAN DA CRUZ	Raised bog	Serras Septentrionais	Atlantic	800	Ramil-Rego 1992
6	TREMOAL DO PEDRIDO	Raised bog	Serras Septentrionais	Atlantic	695	Peiteado-Varela 2017
7	BARREIRAS DO LAGO	Blanket bog	Serras Septentrionais	Atlantic	932	Present study
8	TREMOAL DE LADEIRAS DO CADRAMÓN	Fen	Serras Septentrionais	Atlantic	700	Sá-Otero <i>et al.</i> 2005
9	BORRALLEIRAS DA CAL GRANDE	Blanket bog	Serras Septentrionais	Atlantic	670	Present study; Pontevedra-Pombal <i>et al.</i> 2013
10	TREMOAL DOS MONTES DO BUIO	Blanket bog	Serras Septentrionais	Atlantic	580	Menéndez Amor & Florschütz 1961
11	TREMOAL DE VIVEIRO	Blanket bog	Serras Septentrionais	Atlantic	620	Van Mourik 1986
12	CHAO DE LAGOZAS	Fen	Serras Septentrionais	Atlantic	520	Sá-Otero <i>et al.</i> 2005
13	TREMOAL DE LOBEIRAS	Fen	Serras Septentrionais	Atlantic	660	Sá-Otero <i>et al.</i> 2005
14	TREMOAL DA PENA VEIRA	Fen	Serras Septentrionais	Atlantic	731	Ramil-Rego 1992
15	PENA VELLA	Fen	Serras Septentrionais	Atlantic	700	Ramil-Rego <i>et al.</i> 1994
16	TREMOAL DA GAÑIDOIRA	Fen	Serras Septentrionais	Atlantic	720	Ramil-Rego <i>et al.</i> 1993
17	TURBERA DE SEVER	Fen	Serras Septentrionais	Atlantic	719	Ramil-Rego & Aira Rodríguez 1993b
18	BRAÑA DE BRINS	Fen	Macizo Central	Atlantic	350	Van Mourik 1986
19	TURBERA DE A INSUA	Fen	Macizo Central	Atlantic	740	Taboada Castro <i>et al.</i> 1993
20	TURBERA DE AMENEIROS	Fen	Macizo Central	Atlantic	700	Taboada Castro <i>et al.</i> 1993
21	TURBERA DE CRUZ DO BOCELO	Fen	Macizo Central	Atlantic	730	Silva-Sánchez <i>et al.</i> 2014
22	TURBERA DE MUIÑO	Fen	Macizo Central	Atlantic	690	Taboada Castro <i>et al.</i> 1993
23	TURBERA DE A LAGOA	Fen	Macizo Central	Atlantic	700	Taboada Castro <i>et al.</i> 1993
24	TURBERA DE SUÁRBOL	Fen	Serras Orientais	Atlantic	1080	Pontevedra-Pombal 2002
25	BRAÑA DE LAMELAS	Fen	Serras Orientais	Atlantic	1280	Pontevedra-Pombal 2002
26	BRAÑA DE PORTO ANCARES	Fen	Serras Orientais	Atlantic	1580	Pontevedra-Pombal 2002
27	CAMPA DA CESPEDOSA	Fen	Serras Orientais	Atlantic	1415	Pontevedra-Pombal 2002
28	LAGOA DE LUCENZA	Fen	Serras Orientais	Atlantic	1375	Muñoz Sobrino <i>et al.</i> 2001
29	LAGOA DE ANTELA	Fen	Depresión de Xinzo de Limia	Atlantic	611	Van Mourik 1986
30	TURBERA DE TOIRIZ	Fen	Depresión de Monforte	Atlantic	530	Van Mourik 1986
31	CHAIRA DE PEDRAFITA	Fen	Serras Surorientais	Atlantic	1300	Menéndez Amor 1971
32	TURBERA DE AS AGUILLADAS	Fen	Serras Surorientais	Atlantic	1580	Santos 2004
33	LAGOA DO MARINHO	Fen	Serra do Geres	Atlantic-Mediterranean	1150	Muñoz Sobrino 2001
34	CHARCA DE SANGUIJUELAS o LLEGUNA	Fen	Montes de León	Mediterranean	1100	Menéndez Amor & Florschütz 1961
35	LAGUNA DE SANGUIJUELAS	Fen	Montes de León	Mediterranean	1080	Muñoz Sobrino <i>et al.</i> 2004

Number	Peatland	Type	Sector	N2000 Network Bioclimatic Zone	Altitude (m a.s.l.)	Reference
36	TURBERA DE BRAÑULAS	Fen	Montes de León	Mediterranean	1000	Muñoz Sobrino 2001
37	TURBERA DE XAN DE LLAMAS	Fen	Montes de León	Mediterranean	1500	Morales-Molino <i>et al.</i> 2011
38	TURBERA DE AYOÓ	Fen	Meseta Septentrional	Mediterranean	78	Morales-Molino & García-Antón 2014
39	TURBERA DE CAMPORREDONDO	Fen	Meseta Septentrional	Mediterranean	800	García-Antón <i>et al.</i> 2011
40	TURBERA DE MONTE AREO	Fen	Cantábrica Prelitoral	Atlantic	200	López-Merino <i>et al.</i> 2010
41	TURBERA DE ROÑANZAS	Raised bog	Cantábrica Prelitoral	Atlantic	250	Moreno <i>et al.</i> 2009
42	TURBERA DE LAS CONCHAS	Fen	Cantábrica Prelitoral	Atlantic	363	Ortiz <i>et al.</i> 2016
43	TURBERA DE HUELGA DE BAYAS	Fen	Cantábrica Prelitoral	Atlantic	110	López-Días <i>et al.</i> 2010
44	TURBERA DE LA MOLINA	Raised bog	Cantábrica Prelitoral	Atlantic	650	Martínez Cortizas <i>et al.</i> 2016
45	TURBERA DE LA MOLINA DE VIESGO	Raised bog	Cantábrica Prelitoral	Atlantic	484	Pérez-Obiol <i>et al.</i> 2016
46	TURBERA DE PINAR DE LILLO	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	1360	García-Antón <i>et al.</i> 1997
47	TURBERA DE LILLO	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	1500	Muñoz Sobrino 2001
48	TURBERA DE LA PIEDRA	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	950	Muñoz Sobrino 2001
49	TURBERA DE HERBOSA	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	847	Menéndez Amor 1968
50	TURBERA DE LOS TORNOS	Blanket bog	Cordillera Cantábrica Norte	Atlantic	920	Peñalba 1994
51	TURBERA DE ALSA	Fen	Cordillera Cantábrica Norte	Atlantic	560	Mariscal 1993
52	TURBERA DE CUETO DE LA AVELLANOSA	Blanket bog	Cordillera Cantábrica Norte	Atlantic	1320	J.A. López-Sáez (unpublished data)
53	TURBERA DE CULAZÓN	Fen	Cordillera Cantábrica Norte	Atlantic	592	López-Sáez <i>et al.</i> 2013
54	TURBERA DE PENA VELOSA	Fen	Cordillera Cantábrica Norte	Atlantic	1350	Muñoz Sobrino <i>et al.</i> 2012
55	TURBERA DE COMELLA	Fen	Cordillera Cantábrica Norte	Atlantic	834	Ruiz Zapata <i>et al.</i> 2002
56	TURBERA DE SALDROPO	Raised bog	Montes Vascos	Atlantic	625	García-Antón <i>et al.</i> 1989.
57	TURBERA DE ZALAMA	Blanket bog	Montes Vascos	Atlantic	1330	Pérez-Díaz <i>et al.</i> 2016
58	TURBERA DE USABELARTZA	Fen	Montes Vascos	Atlantic	620	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
59	TURBERA DE LAZAGORRIA	Fen	Montes Vascos	Atlantic-Mediterranean	770	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
60	TURBERA DE GALBANITURRI	Fen	Montes Vascos	Atlantic-Mediterranean	750	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
61	TURBERA DE ARRIZULO	Fen	Montes Vascos	Atlantic-Mediterranean	760	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
62	TURBERA DE VERDEOSPESOA-1	Fen	Montes Vascos	Atlantic	980	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
63	TURBERA DE VERDEOSPESOA-2	Fen	Montes Vascos	Atlantic	100	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
64	TURBERA DE QUINTO REAL	Fen	Pirineos	Alpine	910	Galop <i>et al.</i> 2001
65	TURBERA DE ATXURI	Fen	Pirineos	Alpine	500	Galop <i>et al.</i> 2004
66	TURBERA DE BELATE	Fen	Pirineos	Alpine	847	Peñalba 1994
67	TURBERA DE GESALETA	Fen	Pirineos	Alpine	900	Present study
68	TURBERA DE EL PORTALET	Fen	Pirineos	Alpine	1802	González-Sampériz <i>et al.</i> 2006
69	TURBERA DE RIU DELS ORRIS	Fen	Pirineos	Alpine	2390	Ejarque <i>et al.</i> 2010
70	TURBERA DE BOSC DELS ESTANYONS	Fen	Pirineos	Alpine	2180	Miras <i>et al.</i> 2007
71	TURBERA DEL LAGO BURG	Fen	Pirineos	Alpine	1821	Pélachs <i>et al.</i> 2007
72	TURBERA DEL PRADELL	Fen	Pirineos	Alpine	1975	Ejarque <i>et al.</i> 2009

Number	Peatland	Type	Sector	N2000 Network Bioclimatic Zone	Altitude (m a.s.l.)	Reference
73	TURBERA DE OJOS DEL TREMEDAL	Fen	Montes Universales	Mediterranean	1650	Stevenson 2000
74	TURBERA DE HOYOS DE IREGUA	Fen	Sistema Ibérico	Mediterranean	1780	Gil García <i>et al.</i> 2002
75	LAGUNA NAVA	Fen	Sistema Ibérico	Mediterranean	1190	Gil García <i>et al.</i> 1996
76	TRAMPAL DE NIEVA	Fen	Sistema Ibérico	Mediterranean	1100	Gil García <i>et al.</i> 2001
77	TURBERA DE LAGUNA DE LAS PARDILLAS	Fen	Sistema Ibérico	Mediterranean	1850	Sánchez-Gofi & Hannon 1999
78	NEILA HOLLOW	Fen	Sistema Ibérico	Mediterranean	1480	Von Engelbrechten 1998
79	SUPRALAGUNA NEGRA	Fen	Sistema Ibérico	Mediterranean	1840	Gómez-Lobo 1993
80	TURBERA DE PELAGALLINAS	Fen	Sistema Central	Mediterranean	1340	Franco-Múgica <i>et al.</i> 2001
81	TURBERA DE RASCAFRÍA	Fen	Sistema Central	Mediterranean	1113	Franco-Múgica <i>et al.</i> 1998
82	TURBERA DE NAVACERRADA	Fen	Sistema Central	Mediterranean	1340	Franco-Múgica 1995
83	TURBERA DEL PUERTO DEL PICO	Fen	Sistema Central	Mediterranean	1395	López-Sáez <i>et al.</i> 2016
84	TURBERA DE PUERTO DE SERRANILLOS	Fen	Sistema Central	Mediterranean	1700	López-Merino <i>et al.</i> 2009
85	TURBERA DE NAVARREDONDA	Fen	Sistema Central	Mediterranean	1550	Franco-Múgica <i>et al.</i> 1997
86	TURBERA DE HOYOS DEL ESPINO	Fen	Sistema Central	Mediterranean	1450	Franco-Múgica 1995
87	TURBERA DE NAVALGUIJO	Fen	Sistema Central	Mediterranean	1200	Franco-Múgica 1995
88	TURBERA DE OJOS ALBOS	Fen	Sistema Central	Mediterranean	1483	Blanco-González <i>et al.</i> 2009.
89	TURBERA DE LANZAHITA	Fen	Sistema Central	Mediterranean	588	López-Sáez <i>et al.</i> 2010
90	TURBERA DE PRADO DE LAS ZORRAS	Fen	Sistema Central	Mediterranean	1650	Andrade 1994
91	TURBERA DE PEÑA NEGRA	Fen	Sistema Central	Mediterranean	1000	Abel-Schaad & López-Sáez 2013
92	TURBERA DE GARGANTA DEL TRAMPAL	Fen	Sistema Central	Mediterranean	1440	Atienza Ballano 1993
93	TURBERA DE LA MESEGUERA	Fen	Sistema Central	Mediterranean	900	Abel-Schaad <i>et al.</i> 2014
94	TURBERA DEL MAÍLLO	Fen	Sistema Central	Mediterranean	1100	Morales-Molino <i>et al.</i> 2013
95	TURBERA DEL PAYO	Fen	Sistema Central	Mediterranean	1000	Silva-Sánchez <i>et al.</i> 2016
96	LAGOA COMPRIDA 1	Fen	Serra da Estrela	Mediterranean	1600	Janssen & Woldringh 1981
97	TURBERA DE PATATEROS	Fen	Montes de Toledo	Mediterranean	700	Dorado-Valiño <i>et al.</i> 2014a
98	TURBERA DE VALDEYERNOS	Fen	Montes de Toledo	Mediterranean	850	Dorado-Valiño <i>et al.</i> 2014b
99	TURBERA DE GARGANTA DEL MESTO	Fen	Montes de Toledo	Mediterranean	1000	Gil-Romera <i>et al.</i> 2008
100	TURBERA DE BERMÚ	Fen	Montes de Toledo	Mediterranean	787	J.A. López-Sáez (unpublished data)
101	TURBERA DE LA BOTIJA	Fen	Montes de Toledo	Mediterranean	745	J.A. López-Sáez (unpublished data)
102	TURBERA DE LAS LANCHAS	Fen	Montes de Toledo	Mediterranean	757	J.A. López-Sáez (unpublished data)
103	LAGOA TRAVESSA	Fen	Depresión Atlántica	Mediterranean	10	Mateus 1989
104	TURBERA DE TORREBLANCA	Fen	Costa del Azahar	Mediterranean	0	Menéndez Amor & Florschütz 1961
105	TURBERA TU DE TORREBLANCA	Fen	Costa del Azahar	Mediterranean	0	Dupré-Ollivier <i>et al.</i> 1994
106	TURBERA DE PADUL	Fen	Sistema Penibético	Mediterranean	1900	Carrión <i>et al.</i> 2007
107	TURBERA DEL ACEBRÓN	Fen	Depresión Bética	Mediterranean	25	Stevenson & Moore 1988
108	LAGUNA DE LAS MADRES	Fen	Depresión Bética	Mediterranean	7	Stevenson 1985